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CITATION:

Adachi, Toshihisa. Necessity of Geotechnical Data Base and of Reliable Technical Committees for the Civil Engineering Projects. Proceeding of TC302 Symposium Osaka 2011 : International Symposium on Backwards Problem in Geotechnical Engineering a ...

ISSUE DATE:

2011

URL:

<http://hdl.handle.net/2433/173828>

RIGHT:

## Necessity of Geotechnical Data Base and of Reliable Technical Committees for the Civil Engineering Projects



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**ABSTRACT:** In order to safely and soundly construct any civil engineering infrastructure and to predict the liquefaction potential as well as the seismic intensity, it is very important to have a reliable geotechnical data base and also to constitute an effective scientific and technical committee. At first, this paper describes the outline of geotechnical database, “Kansai Geo-Informatics Database (GI-base)”, that was created by a consortium of geotechnical engineers/researchers and their affiliated organizations in Kansai region of Japan; the KG-NET (**K**ansai **G**eo-informatics **N**etwork). Then, it emphasizes that the geotechnical engineers must have the knowledge of subsurface structure in addition to that of soil properties. Finally, it introduces the case history of a successfully disbanded technical committee for the Nakanoshima railway line (subway) construction project which consisted of members not only from universities, owner and administrative organizations, but also from contractors. The committee greatly contributed to the successful completion of the Nakanoshima line.

### 1 INTRODUCTION

In this paper, at first, the usefulness of GI-base and its historical development are represented. The history of geo-informatics research in which geology and geotechnics have been closely collaborated is one of the key factors for the successful achievement of GI-base. The Kansai region is the second largest area where old capitals of Japan such as Osaka, Nara, and Kyoto are located. These cities have been developed mainly on low, flat and alluvial plains. In addition to Osaka, Kobe and many other cities are developed in the Osaka Plains and along the coast of the Osaka Bay where soft grounds are widely spread. Thus the development of these cities required careful site investigations with a very large number of borehole studies to construct much of needed infrastructures, such as highways, railways, lifelines, and airport constructions, as well as to establish disaster prevention countermeasures.

Secondary, it stresses the importance of knowledge of subsurface structure by showing a case history. Finally, a technical committee, which was banded to support the construction of the Nakanoshima Railway Line, is discussed. In the history, the railway and ground transportation networks have been taking over the role of the river transportation in Osaka. Now, Nakanoshima Island is the area of increasing high-density land use, therefore the improvement of the transportation links is required. Nakanoshima Line is in the symbolic island of water metropolis of Osaka, and it will not only contribute to the further economic development but also provide a direct link with the central and northern area of Kyoto city via Keihan Main Line. Furthermore, Nakanoshima Line will contribute to improvement of the transportation network in Kansai region.

Since the construction had to be done under very severe conditions, not only geotechnical but also surrounding environmental conditions, it was needed to establish a technical committee, which

consisted of both academic researchers and practical engineers. The committee greatly contributed to the successful completion of the Nakanoshima Line.

## 2. GI-BASE AND ITS HISTORY

### 2.1 Outline GI-Base

The Geo-Information Database in Kansai (GI-base) was constructed by gathering a very large amount of borehole investigation data obtained in many projects of urban construction in Kansai region, such as the construction of manmade islands, subways, lifeline, etc.

Fig. 1 shows the locations of more than 48,000 boring data, which have been collected and digitized. Through geological and geotechnical interpretations, GI-base has been developed and updated. Cross-section view of the required underground can easily be drawn on personal computers together with various soil properties such as classification, gradation, the thickness of each layer, ground water level,  $N_{SPT}$  values and so on. The history of geo-informatics research in which geology and geotechnics have been closely collaborated is one of the key factors for the successful achievement of GI-base.

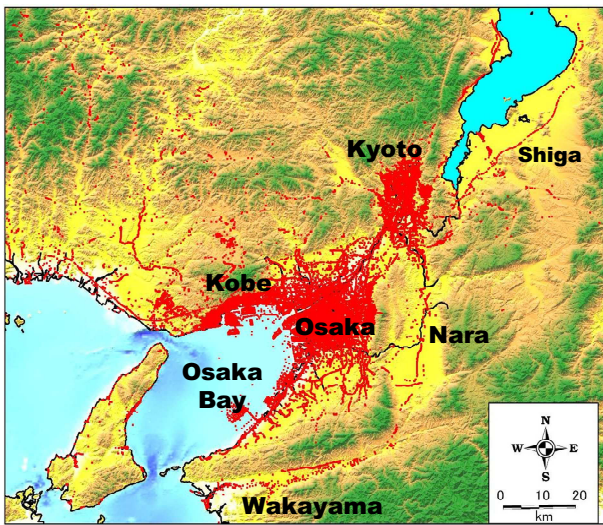


Fig. 1 Distribution of boreholes in GI-base

### 2.2 Historical Developments of KG-NET

Fig. 2 shows the chronology of how the KG-NET was developed from the starting organization of the Research Committee on Sea-bed Deposit of Osaka Bay (1984-1991). Before the geotechnical researches by this committee, there have been several research groups under the Kansai Branch of Japanese Geotechnical Society (JGS) studying the

geotechnical and geological features of the Osaka Basin by collecting significant amounts of

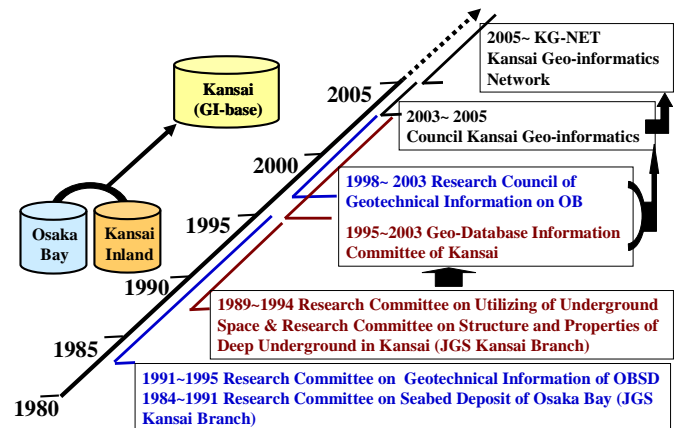


Fig. 2 Historical developments of GI-base and KG-NET

borehole data, and there have been publications of “Osaka Ground” (a collection of soil boring logs) in 1970, and “A New version of Osaka Ground” in 1987, although no digital borehole database was created.

Borehole investigations for the Kansai International Airport and Phoenix Project (landfills for waste disposals) have started one after another in the Osaka Bay around 1980. Extensive investigations of the Osaka Bay seabed were necessary for the waterfront development, and archiving of data in digital form by GRI became routine with the development of computers. The Research Committee on Seabed Deposit of Osaka Bay (1984-1991, Chairperson, Prof. K. Akai) was established first by the Kansai Branch of JGS. This activity was succeeded to the Research Committee on Osaka Bay Geo-Informatics and Utilization (1991-1995, Prof. T. Matsui), and the Research Council of Osaka Bay Geo-Informatics (1995-2003). Through these research activities, “Geo-Informatics Databases in Osaka Bay Area” (GI-base OB) was constructed.

On the other hand, the Research Committee on Underground Space Utilization (1989-1994, Chairperson, Prof. T. Adachi) was established, and this committee dealt mainly with public sector’s infrastructure to utilize deep underground spaces in the large cities (Osaka, Kobe, and Kyoto). This committee worked together with the Research Committee on Structure and Properties of Deep Underground in Kansai Branch of JGS (1989-1992). This activity was succeeded to the Geo-Informatics Committee of Kansai (1995-2003). During these research activities, “Geo-Informatics Databases in Kansai Inland” (GI-base K) was constructed.

These two databases were integrated into a single system in 2003, and the whole data was managed under an organization of the Council of Kansai Geo-informatics (2003-2005). Further in 2005, it is recognized to form “Kansai Geo-Informatics Network (KG-NET Chaired by )”.

### 2.3 Geotechnical Fragility Mapping in Terms of Seismic Intensity Due to Expected Uemachi Earthquake

A representative cross-sectional view of subsurface ground for Osaka Plain is shown in Fig. 3. The selected line is the one along the subway Chuo Line from the coast of Osaka Bay to Ikoma Mountain. Uemachi Upland is located in the heart of Osaka where all strata are tilting by the prevalence of flexure structure developed by the tectonic movement of the Uemachi Fault.

cene clay in this region is well known as sensitive clay.

In the practice of earthquake disaster prevention and mitigation for a wide area, estimate of the damage that will be caused by the earthquake of target area is generally performed. And then, local governments draw up the regional plan for disaster prevention based on the information of volume and locations of damages due to earthquake. The prediction of earthquake behavior, such as seismic intensity, liquefaction occurrence, and others, is very vital, as its results become the basis of evaluating earthquake damages.

As previously mentioned, GI-base could be a versatile tool to provide necessary input of underground geometry as well as dynamic properties of the strata. In the practical sense, the regional distribution of hazardous area against high seismic intensity and liquefaction due to earthquake can

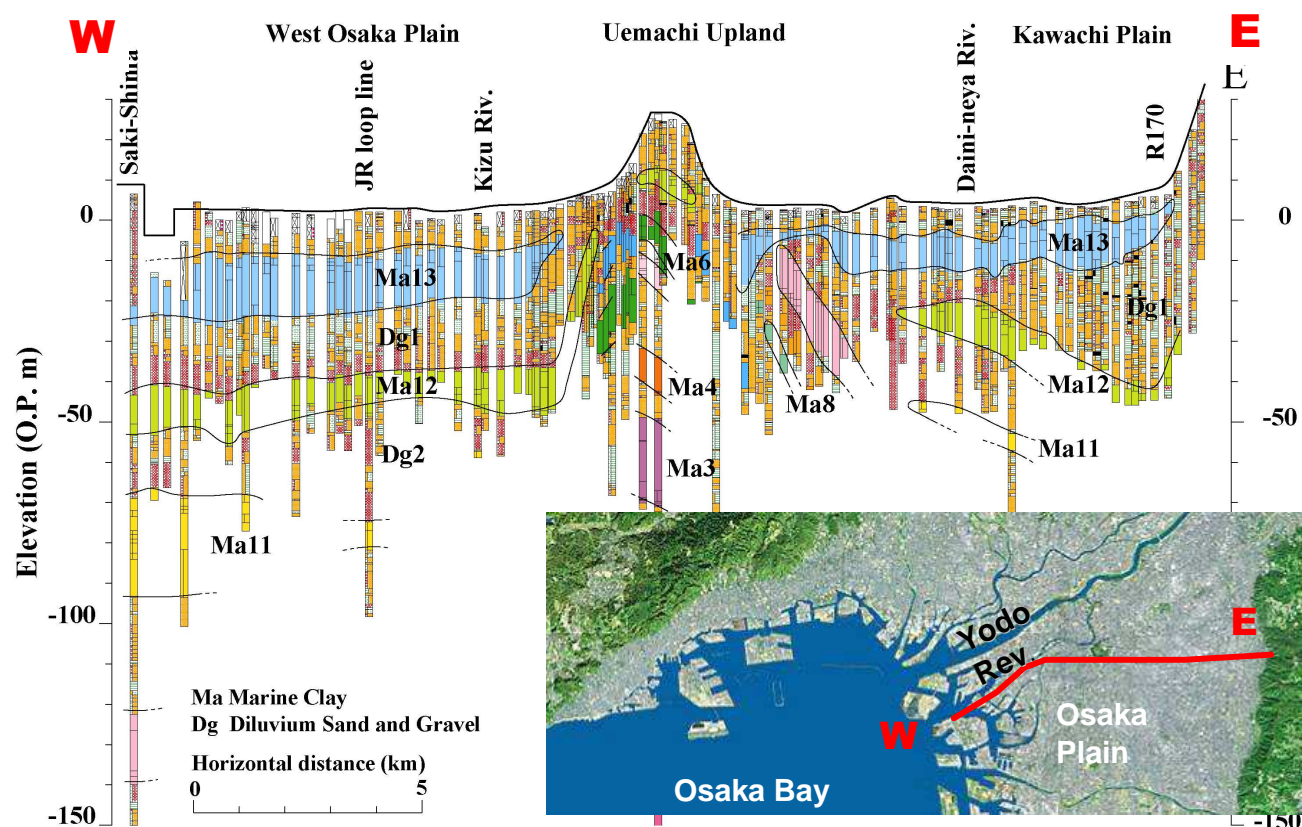


Fig. 3 Cross-sectional view of subsurface ground for Osaka Plain

On the west side of Osaka, the thick Holocene marine clay (Ma 13) layer exists underlain by the Pleistocene gravel layer and the alternating Pleistocene deposits. The strata are rather stable and horizontal deposited. On the eastern part of Osaka, the basin structure can be seen between the Uemachi Upland and the Ikoma Mountains. The Holo-

provide very important and useful information for disaster mitigation.

Let us pay attention to the distribution of the upper Holocene sand and clay layers in Osaka Plain and the surrounding area because those layers intensify seismic intensity and can be fragile for liquefaction. Distribution of the thickness of the up-



per Holocene sand and clay layers is illustrated in Fig.4. The Holocene layers can be seen at almost whole area of Osaka Plain. Along the coastal line and the rivers, the thickness of the Holocene layers tends to be larger (more than 30 m).

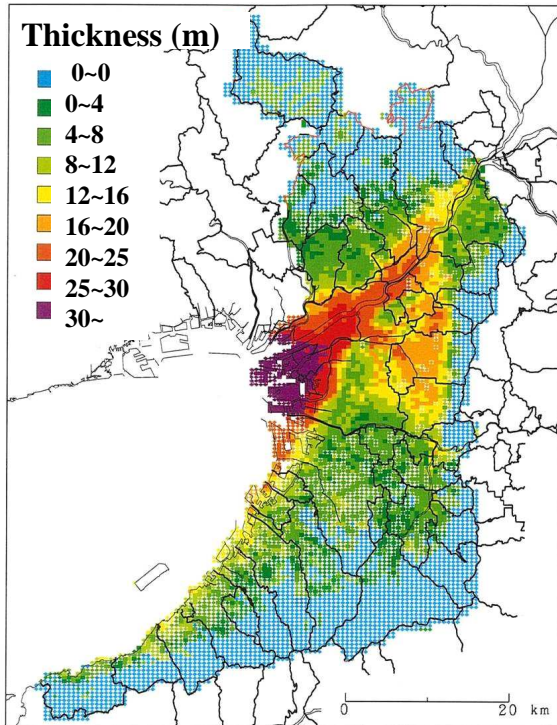


Fig. 4 Thickness distribution of Holocene Deposits based on the GI-base for Osaka Plain

The distribution of strong ground motion, that is, the seismic intensity in Japanese Scale, due to the expected Uemachi earthquake motion, which is estimated based on GI-base, is shown in Fig.5. Generally speaking, the high seismic intensity zone is corresponding to the area having thick Holocene layer, however, it is very important to realize that the highest seismic intensity zone is estimated to be along the Uemachi Fault.

In this paper, the results of liquefaction estimation are not presented. However, as already made clear, it is ascertained that GI-base can give an academic knowledge to understand the local underground conditions as well as the primary inputs to evaluate the expected geo-hazard such as liquefaction due to earthquake. The liquefaction fragility for Osaka basin area is evaluated with the simplified method on the basis of GI-base. The calculated results clearly exhibit the local characteristics, i.e. liquefaction will widely take place and induce serious geo-hazard in Osaka Plains, and along the coast of Kobe and the adjacent area. It is also found that the distribution of the previous locations of liquefaction occurrence in Osaka basin area validates the present performance based on GI-base.

The latest action plan of Osaka local government for Earthquake-induced disaster mitigation has actually been established on the basis of the present outputs of the liquefaction fragility.

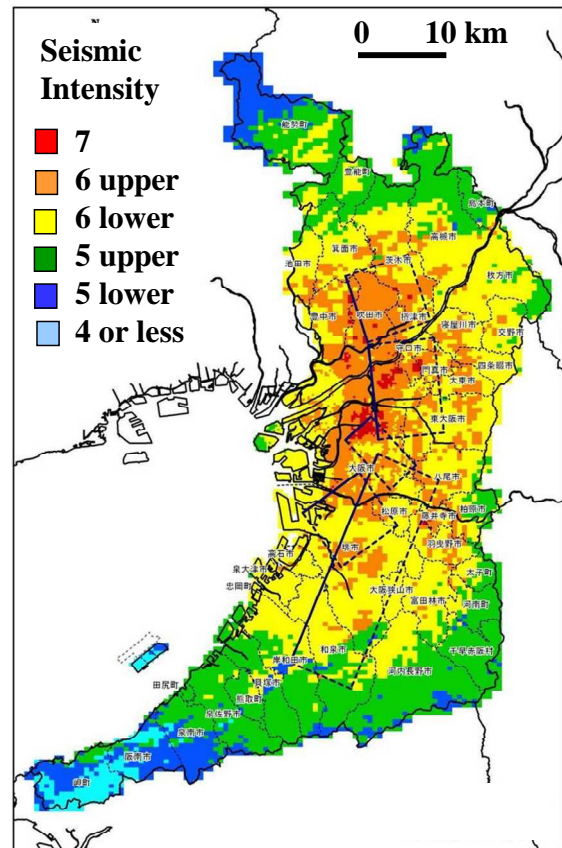


Fig. 5 Estimation of seismic intensity during Uemachi Faults Earthquake

#### 2.4 Required Knowledge of Subsurface Structure

Although there exists the reliable GI-base, sometimes completely different ground formation would be drawn when having not enough knowledge of specific geological structures in the concerning region. Such a case will be introduced as follows. In 2003, the construction of the Hanshin Namba Line, which extends Nishikujyo to Namba, was started as shown in Fig. 6.

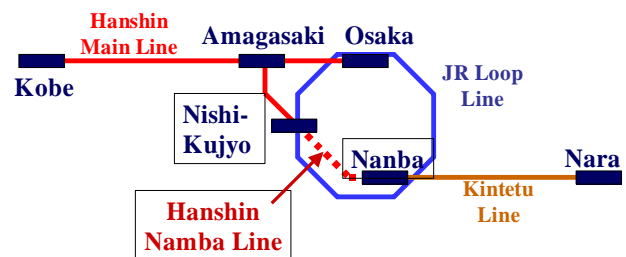
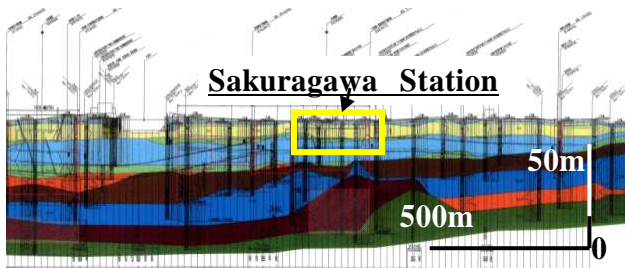
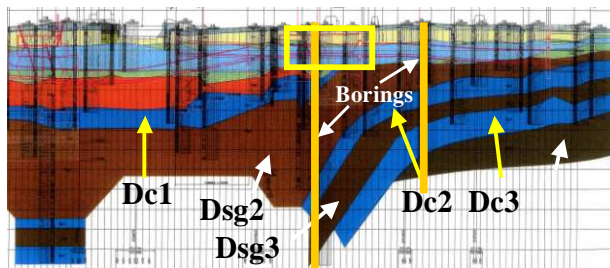


Fig. 6 Hanshin Namba Line directly connecting Kobe to Nara



(a) Initially presented geological profile



(b) Corrected geological profile

Fig. 7 Geological profile around the Sakuragawa Station

In order to support the construction works, the technical advisory committee was established. At a meeting when the construction of the Sakuragawa Station was discussed, the geological profile illustrated in Fig. 7(a) was submitted. Immediately, one of the members made an observation that the geological profile was doubtful, since the Sakuragawa Flexure should intersect the new line around this region as shown in Fig. 8. Then committee requested to carry out additional couple deep borings. The corrected geological profile based on the results clarified by the additional borings is illustrated in Fig. 7(b). From the view point of the construction by cut and cover method, this finding is very important to determine the appropriate selections of the embedded depth of earth retaining wall and cutoff method. Good use of right method, the construction of the station was completed successfully. On March 20, 2009, the line opened from Nishikujo Station to Nanba station

### 3. NECESSITY OF RELIABLE TECHNICAL COMMITTEE AND INTEGRATED DATA & INFORMATION COLLECTING SYSTEM

#### 3.1 Nakanoshima Line

Over countless years, Osaka has been developed historically around the rivers and canals,

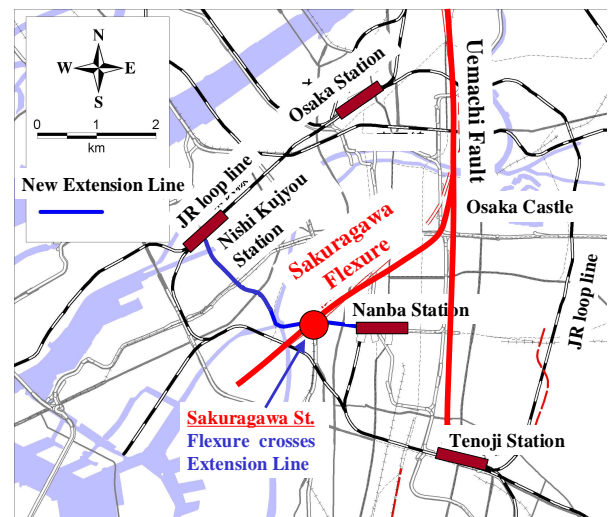


Fig.8 Namba Line and Sakuragawa Flexure

while the former water transportation system was in force. Nakanoshima Island area has been a very valuable place for the activities in Osaka till now because of its location, in the middle of Okawa River (the tributary of Yodo River, used to be the main stream from Kyoto). In the history, the railway and ground transportation networks have been taking over the role of the river transportation in Osaka. Now, Nakanoshima Island is the area of increasing high-density land use, therefore the improvement of the transportation links is required. Nakanoshima Line is in the symbolic island of water metropolis of Osaka, and it will not only contribute to the further economic development but also provide a direct link with the central Osaka and northern area of Kyoto city via Keihan main Line. Namely, the line was made a branch line from the Tenmabashi Station of the main Keihan Line. Therefore, Nakanoshima Line will contribute to improvement of the transportation network in Kansai region.

When this new line project was being put into operation, a vertically separated structure is adopted, which consists of the railway assets holder (Nakanoshima Rapid Railway Co., Ltd.) and the train operators (Keihan Electric Railway Co., Ltd.). However, the construction was taken care by Keihan Electric Railway Co., Ltd., as the site management organization, since it had much construction experiences. Fig. 9 shows the organizational chart for the Nakanoshima Line construction.

Fig. 10 illustrates the alignment of Nakanoshima Line and newly constructed 4 stations. The construction was performed by dividing the total construction section into seven sections and each section was constructed by different contractor.



### 3.2 Establishment of Technical Committee and the Construction Works

Since the construction had to be done under very severe conditions, not only geotechnical but also surrounding environmental conditions, it was needed to establish a technical advisory committee, which consisted of members not only from universities, owner and administrative organizations, but also from contractors. Furthermore, when the meetings were held, even the directors of 7 contractor's offices also had to attend and if necessary they should present the problems at sites and explain how to overcome.

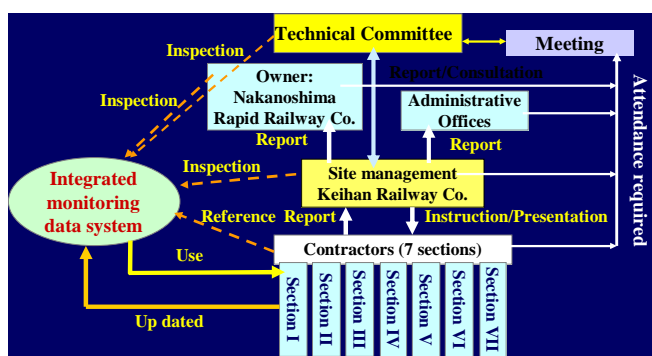


Fig. 9 Organizational chart for the Nakanoshima Line construction, the technical advisory committee, and the integrated monitoring data system

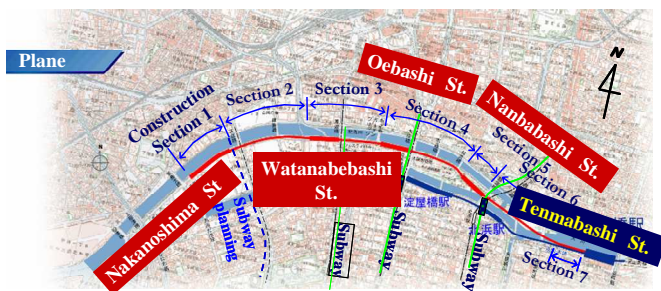


Fig. 10 Nakanoshima Line, 4 new stations, and construction sections

Fig. 11 shows the geological profile along the Nakanoshima Line. As seen in the figure, the ground consists of soft clay layers and complicated subsurface structures. Namely, in western side, alternation of layers of soft clay and hard gravel prevails, while in eastern side the sudden change of layers due to the Uemachi Fault can be seen.

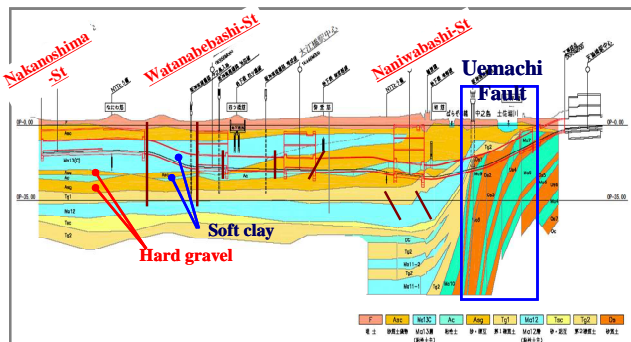


Fig. 11 Geological profile and vertical alignment of Nakanoshima Line

To construct the underground station, the cut and cover method was applied. Especially, since the earth retaining wall is an important step in cut and cover method, we decided to select the reliable earth retaining wall for each stations based on the ground and environmental conditions around the construction site. For the purpose, trial constructions to find out the reliable earth retaining wall were carried out. Based on the trial test results, in the construction of the Nakanoshima, Watanabebashi, and Oebashi Stations the SMW method was, on the other hand the Naniwabashi Station the diaphragm wall was applied as the earth retaining walls.

Observational method was applied by cooperating with all seven construction sections. The monitoring items in the cut and cover construction sites were as follows;

- (1) Temporary works: Horizontal displacement, Stresses in wall, Axial forces in strut, etc.,
- (2) Bottom ground: Pore water pressure, Rebound,
- (3) Surrounding ground: Horizontal displacement, Pore water pressure, Ground surface settlement, etc.
- (4) Neighboring structures: Displacement, Settlement, Slanting, etc.

On the other hand, the tunnels between stations were constructed by shield tunneling method. Two single-line shield tunnels (one going east, the other going west) were opened between each pair of stations. A single shield machine opened two tunnels in a U-turn fashion between the station pairs of Nakanoshima and Watanabebashi, Watanabebashi and Oebashi, and Oebashi and Naniwabashi. However, two machines were used between Naniwabashi and Tenmabashi because the distance between the stations is long and the slope is rather steep. Both launched from the shaft at the edge of Naniwabashi Station and proceeded toward Tenmabashi Station.

The shield tunnels were constructed also under very severe conditions. First of all, they had to cross under the three municipal subways with very

small isolation distance, secondary to run above the active Uemachi Fault and finally to across under the riverbed of the River Tosabori with very thin cover as 4 meter as shown Figs. 10 ,11, and 12 as well as Photo. 1. The monitoring items in the shield tunneling construction sites were as follows;

- (1) Shield machine: Face pressure, Thrust, Cutter torque, Backfill grouting pressure, Pitching, Rolling, and Yawing, etc.
- (2) Surrounding ground: Horizontal and vertical displacements, Surface settlement, Pore water pressure, Temperature, etc.
- (3) Neighboring structures: Displacement, Settlement, Slanting, etc.



Photo. 1 Shield tunnel under the River Tosabori

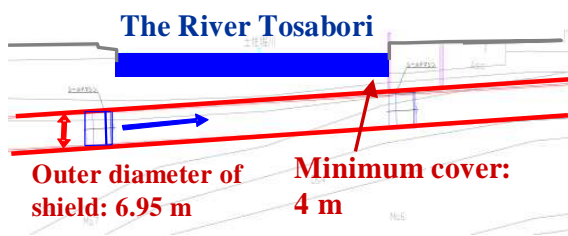


Fig. 12 Minimum cover above shield tunnels

### 3.3 Integrated Data & Information Collecting System

In order to carry out the constructions safely and to minimize the effects on the surrounding area, it was decided to establish the overall integrated information and data collecting system not only for one construction section but for all construction sections. Namely, the central office integrated the information of monitored data from each construction section, and then it evaluated the quality of over all construction progress, the construction safety, and the effect to neighboring region based on the integrated information. Furthermore, the integrated data from all construction sections were disclosed for any engineer at each construction sections and he could see the real time data even of

the other construction section by his own personal computer as shown in Fig. 9.

### 3.4 Counter Measure against Fault Displacement for Nakanoshima Line<sup>2)</sup>

As shown in Figs. 5 and 8, a reverse fault, so called the Uemachi Fault, runs in the very heart of Osaka City in North-South direction. Among various problems, the adopted counter measure in the shield tunnel construction against the flexure deformation due to the Uemachi Fault displacement was discussed in the committee.

The Uemachi Fault was identified under a flat surface ground condition, which is called hidden fault, as shown in Fig. 13.

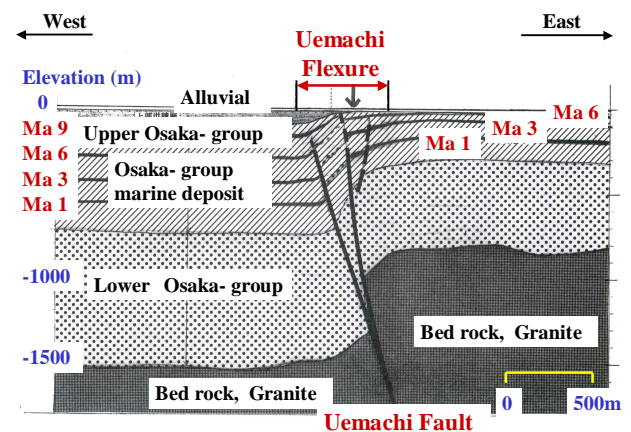


Fig.13 Hidden Uemachi Fault and above flexure

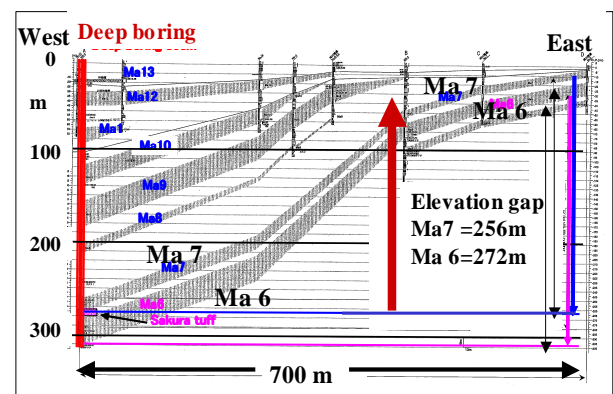


Fig. 14 Uemachi Flexure based on boring studies

Based upon the previous study in the area including the seismic survey, geological borings outside of the flexure structure were planned. The western side boring was long boring of about 300m to reach Ma 6. As shown in Fig.14, the upper most layer in the eastern side was Ma7 of Osaka Group and the same marine clay formation in the western



part was expected to be at about GL-300m. Fig. 14 shows the Uemachi Flexure based on boring studies

The rate of the vertical fault displacement of throw was estimated from the difference in the depths between 256m for Ma7 and 272m for Ma6 and the time periods after the depositions of these layers. The results are shown in Table-1.

Table 1 Estimation of Displacement Rate of Uemachi Fault at Nakanoshima

Soil layer	Deposit era	Base of Sediment		Difference in Height (Throw)	Rate of throw
		West side boring	East side boring		
	$\times 10^3$ year from BP	GL -m	GL -m	m	m/ $10^3$ year
Ma7	577	267.11	11.52	255.59	0.443
Ma6	621	301.40	29.47	271.93	0.438

Namely, the average displacement is estimated as  $0.44\text{m}/10^3\text{year}$ . Sugiyama (2003)<sup>3</sup> reported the last event along the Uemachi Fault is estimated about 9,000 years before and estimated the possible release of the vertical displacement is  $0.44\text{m}/10^3\text{year} \times 9,000\text{years} = 4\text{m}$ . The fault displacement for the design of Nakanoshima line was based upon the displacement of 4m.

The subway tunnel section that is constructed in the Uemachi Flexure with the 700m in width is expected to behave differently according to the magnitude of the fault displacement. That is, the maximum displacement will be expected to be 4m, but it is not necessarily to reach to the maximum level in every event. Introducing the pattern of flexure deformation given in Fig. 15 in the beam theory on elastic foundation, the longitudinal behavior of the shield tunnel was investigated.

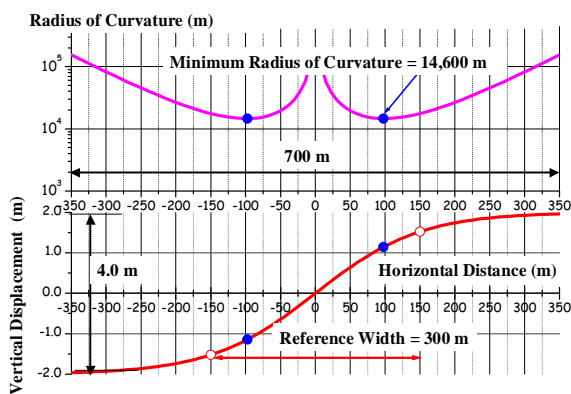


Fig. 15 Deformation Curve

Based upon the study of several cases with different fault displacements and their effect, it was concluded that two types of emergency plan for the countermeasure should be prepared against two different magnitudes of fault displacements. As shown in Fig. 16, in one of the sections of the sub-

way, the vertical alignment had to be designed using steep inclination of 4% so as to run under the riverbed with enough cover to keep the safe tunnel construction. The inclination value 4% is the allowable maximum value for train operation in Japan<sup>4</sup>. Whenever the next Uemachi fault displacement will cause the same amount of deformation for the Uemachi flexure as in the past earthquake, the maximum inclination of the subway exceeds the critical value of 4% and the railway operation is forced to terminate.

However, if the fault displacement is some value less than 4m, say 1 m, the railway vertical alignment can be adjusted to keep the inclination less than 4% if tunnel inner cross-section has set up some room. For instance, if tunnel inner cross section is widened about 10cm vertically and the fault displacement is less than 1m, it can adjust the inclination within the allowable value as shown in Fig.17 and the railway to continue its service even after the earthquake.

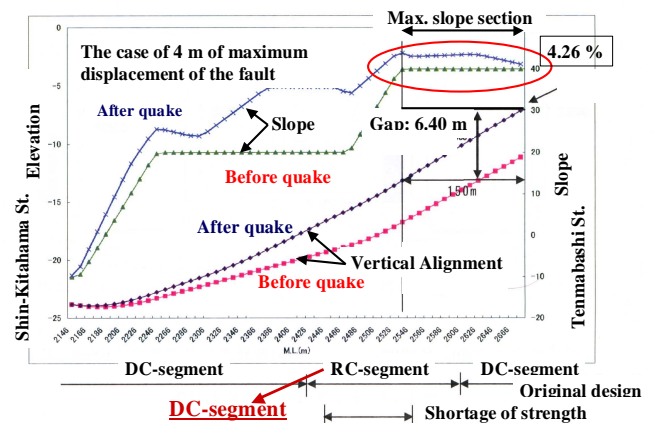


Fig. 16 Vertical alignment before and after fault displacement of 4 m

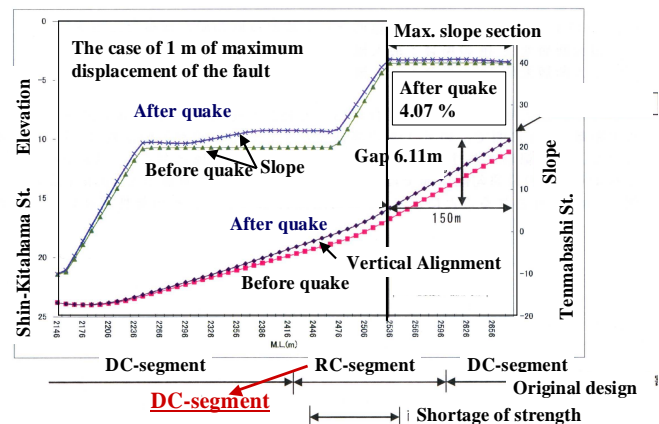


Fig. 17 Vertical alignment before and after fault displacement of 1 m

At any rate, the section of the shield tunnel of 700 m was assigned as affected by the fault displacement. Among various considerable counter-measures to avoid damage of the shield tunnel, it was decided to adapt the ring segments made by ductile steel (DC) rather than precast reinforced concrete (RC) as given in Figs.16 and 17. The moment strength of DC is about 2.5 times larger than that of RC.

## CONCLUSIONS

1. Kansai Geo-information Database (GI-base) has been developed by using more than 48,000 boring data mainly collected from urban area, such as Osaka, Kobe, and Kyoto.
2. It is ascertained that GI-base can give an academic knowledge to understand the local underground conditions as well as the primary inputs to evaluate the geo-hazard such as the seismic intensity and the liquefaction potential due to earthquake.
3. In addition to the knowledge of soil properties, the knowledge of subsurface structure is required to geotechnical engineers.
4. A reliable technical committee and integrated data & information collecting system are required for the successful completion of any important construction projects. The proper counter measure was taken into account in the Nakanoshima Line construction against the Uemachi Fault displacement by supervision of the technical committee

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